Expansive Common Low-cost InterPlanetary Science Explorer (ECLIPSE)

Bringing to Light the Details of the Solar System

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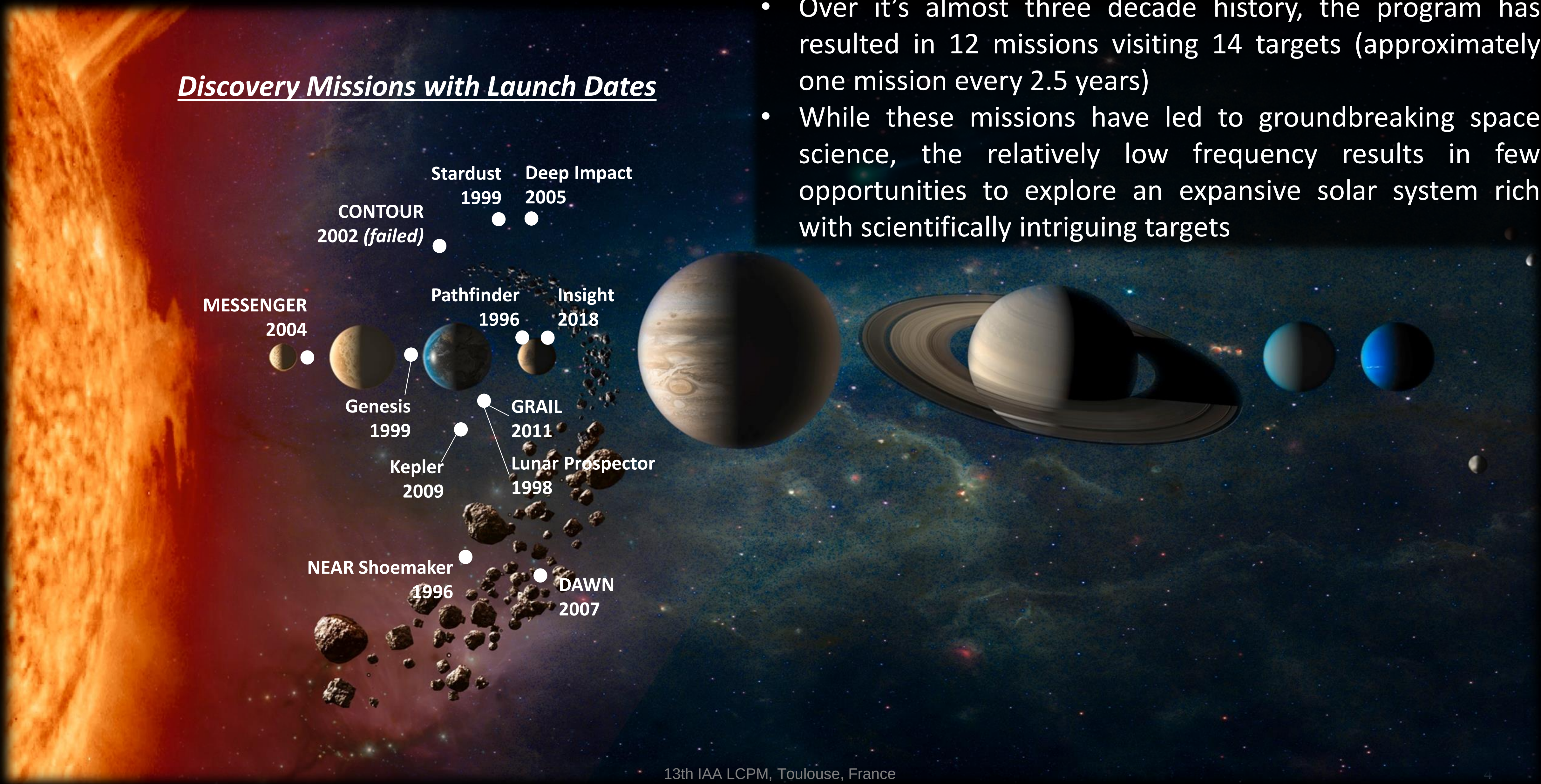
AGENDA

1. Current Practice
2. The Vision
3. Spacecraft and Payload
4. Mission Design
5. Conclusion

CURRENT PRACTICE AND A NEW VISION

CURRENT PRACTICE

- Since its founding in 1992, the Discovery Program has been NASA's foundation for lower cost scientific exploration
- Over it's almost three decade history, the program has resulted in 12 missions visiting 14 targets (approximately one mission every 2.5 years)
- While these missions have led to groundbreaking space science, the relatively low frequency results in few opportunities to explore an expansive solar system rich with scientifically intriguing targets



THE VISION [1/2]

- The ECLIPSE (Expansive Common Low-cost InterPlanetary Science Explorer) concept is based on a different approach to scientific exploration of our solar system that seeks to complement the larger scale Discovery missions but expansively cover even more of the solar system using a rapid deployment architecture
  - Maximizing destinations is a key driver, rather than focusing on missions dedicated to studying 1-2 targets
  - This approach is enabled by the recent growth of the small satellite industry, which presents a new paradigm that allows for a high cadence of missions due to short development timelines and low-cost hardware options
- <u>Primary Goal:</u> To achieve a more holistic understanding of our solar system through the use of spatially distributed, low cost spacecraft with a diverse payload suite capturing the same measurement throughout many destinations
- <u>Supporting Objectives:</u>
  - Maximize scientific opportunity
  - Maximize science return per dollar
  - Provide the ability to rapidly respond to new discoveries by previous missions

THE VISION [2/2]

- This new approach is enabled by
  - Advances in small satellite technologies
  - Standardization of spacecraft buses and payload instruments
  - Improvements in rapid mission design tools and infrastructure
  - Increased access to space through new, low-cost launch vehicle options and more frequent rideshare opportunities
- The ultimate goal is to transition from a single spacecraft every few years to 10s (and eventually perhaps even 100s) of spacecraft every year

Motivated by an Early Pioneer: Voyager and its Grand Tour

Voyager's grand tour gave us an entirely new perspective on our solar system by exploring a broad range of planets and space environments with just two spacecraft.

By leveraging the technological advances since Voyager, we can follow in its footstep and achieve scientific characterization of the solar system at a fraction of the cost.

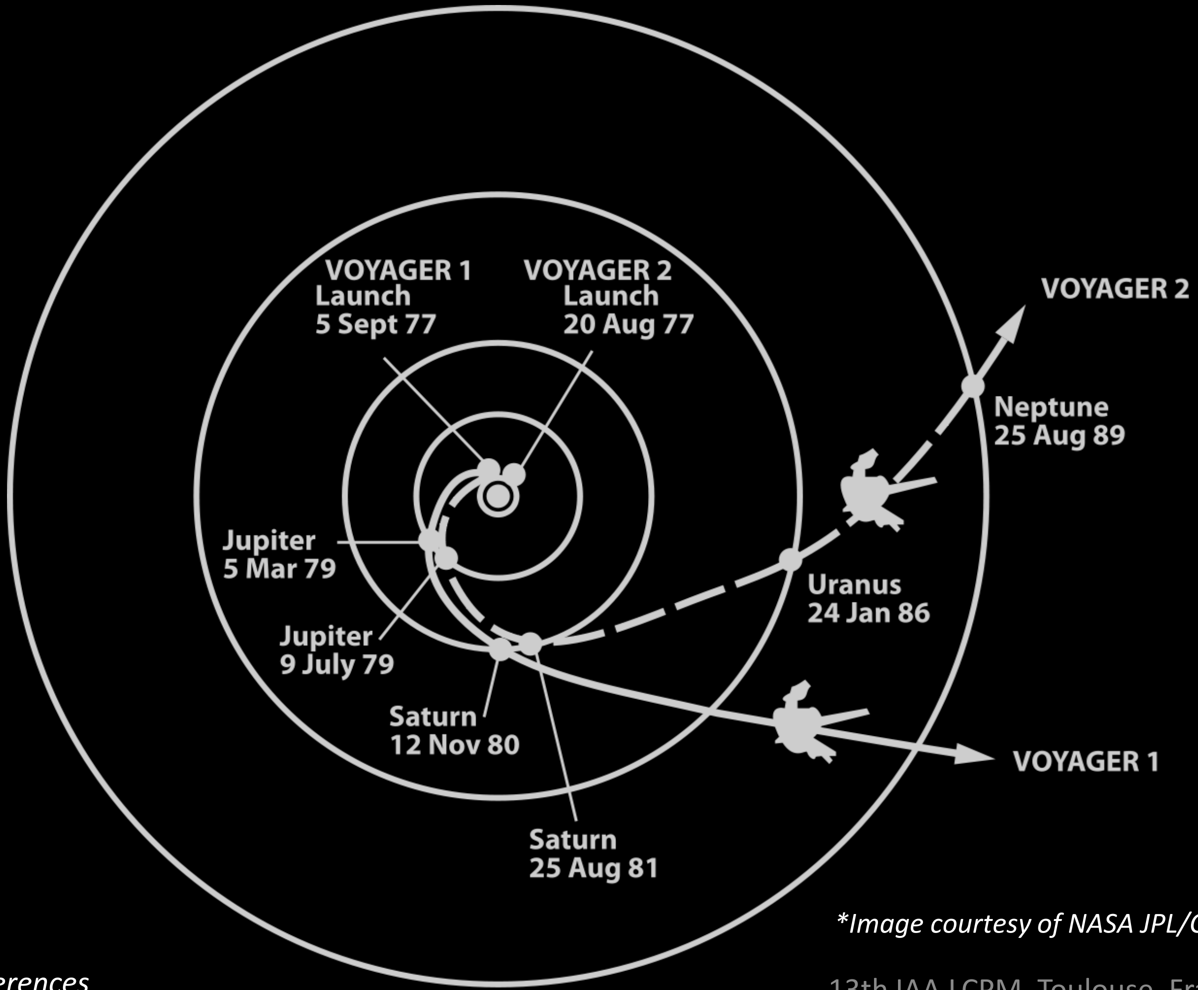
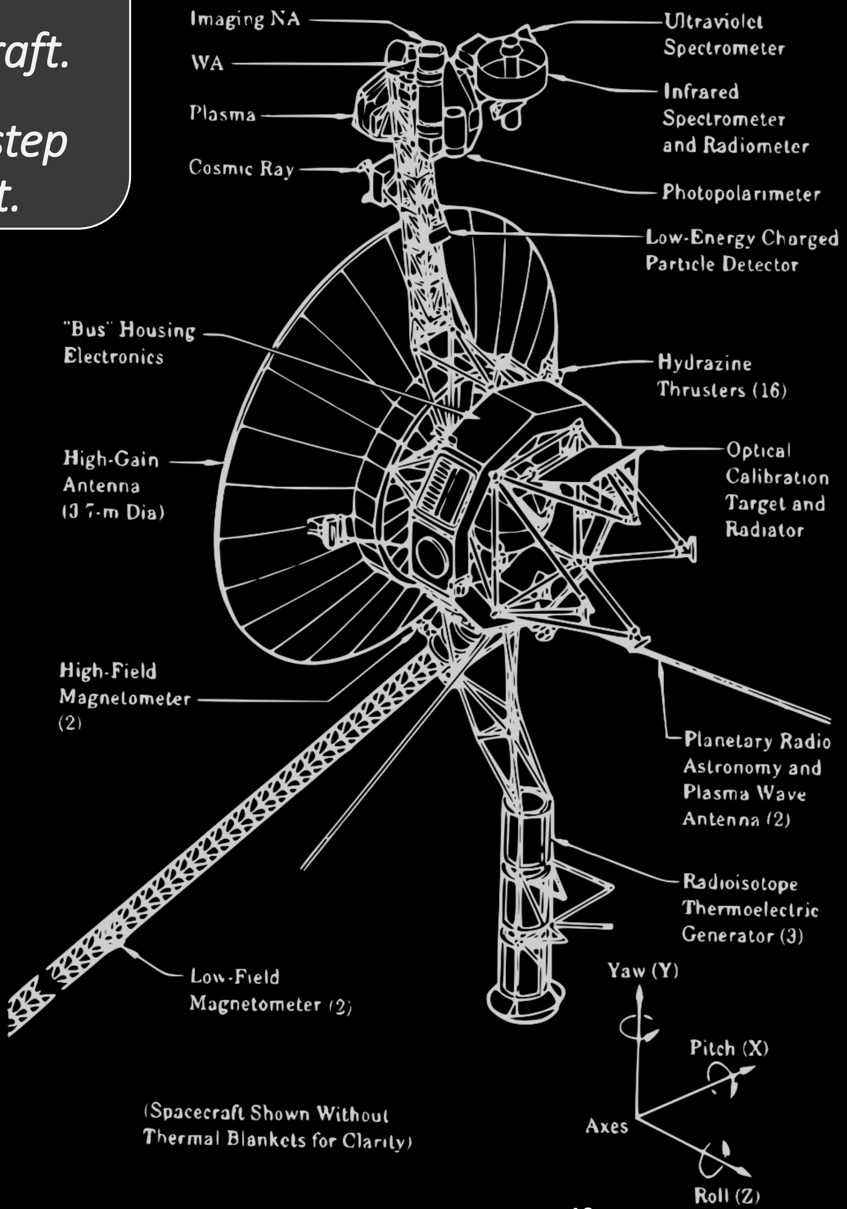


*Image courtesy of NASA JPL/Caltech



Voyager Spacecraft [10]

** Numbered references provided at end of presentation*

The ECLIPSE concept looks to utilize a spacecraft 1/3 the size of Voyager to achieve many times the science return through the use of a low cost, easily producible hardware platform able to be deployed to multiple destinations.

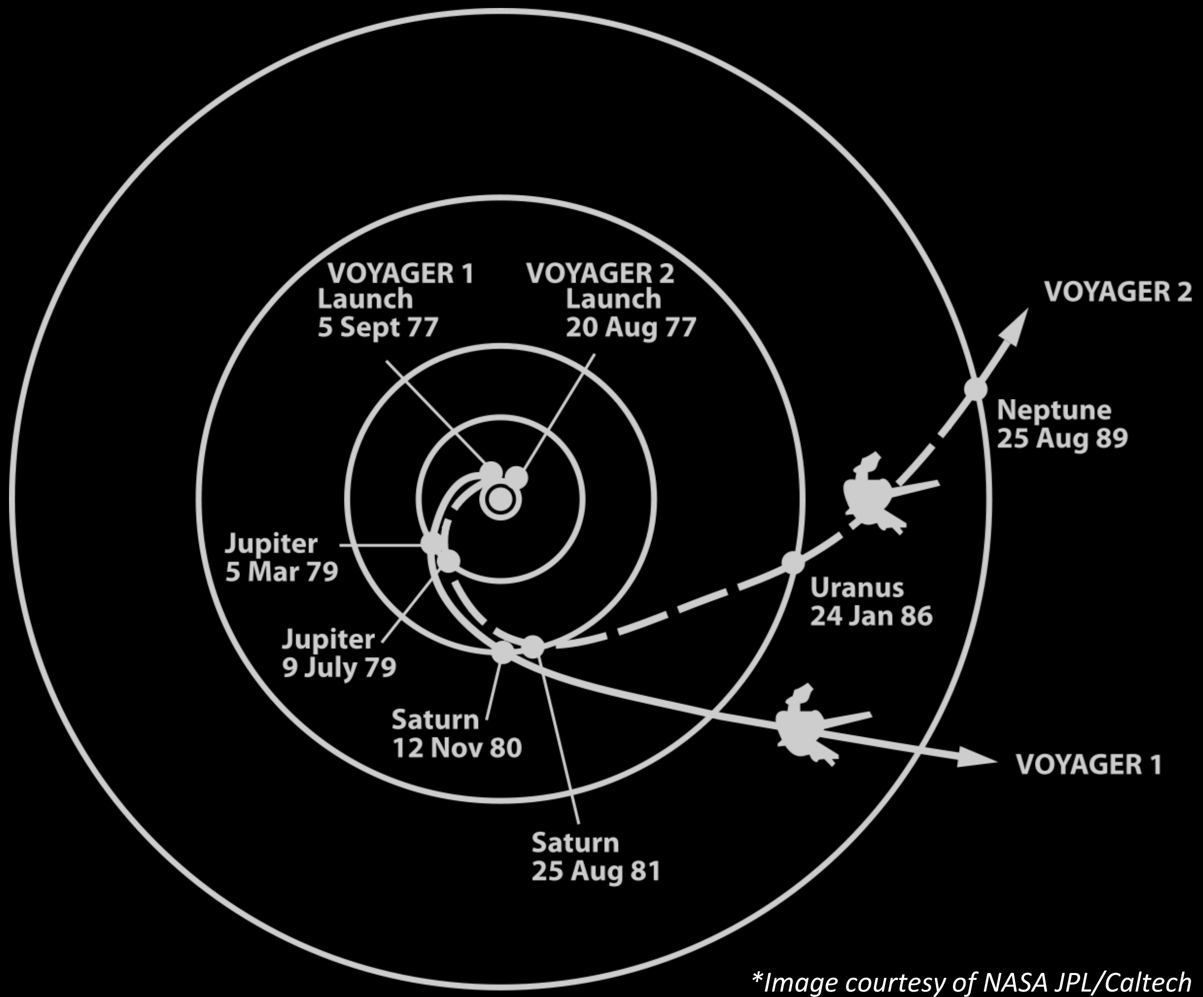
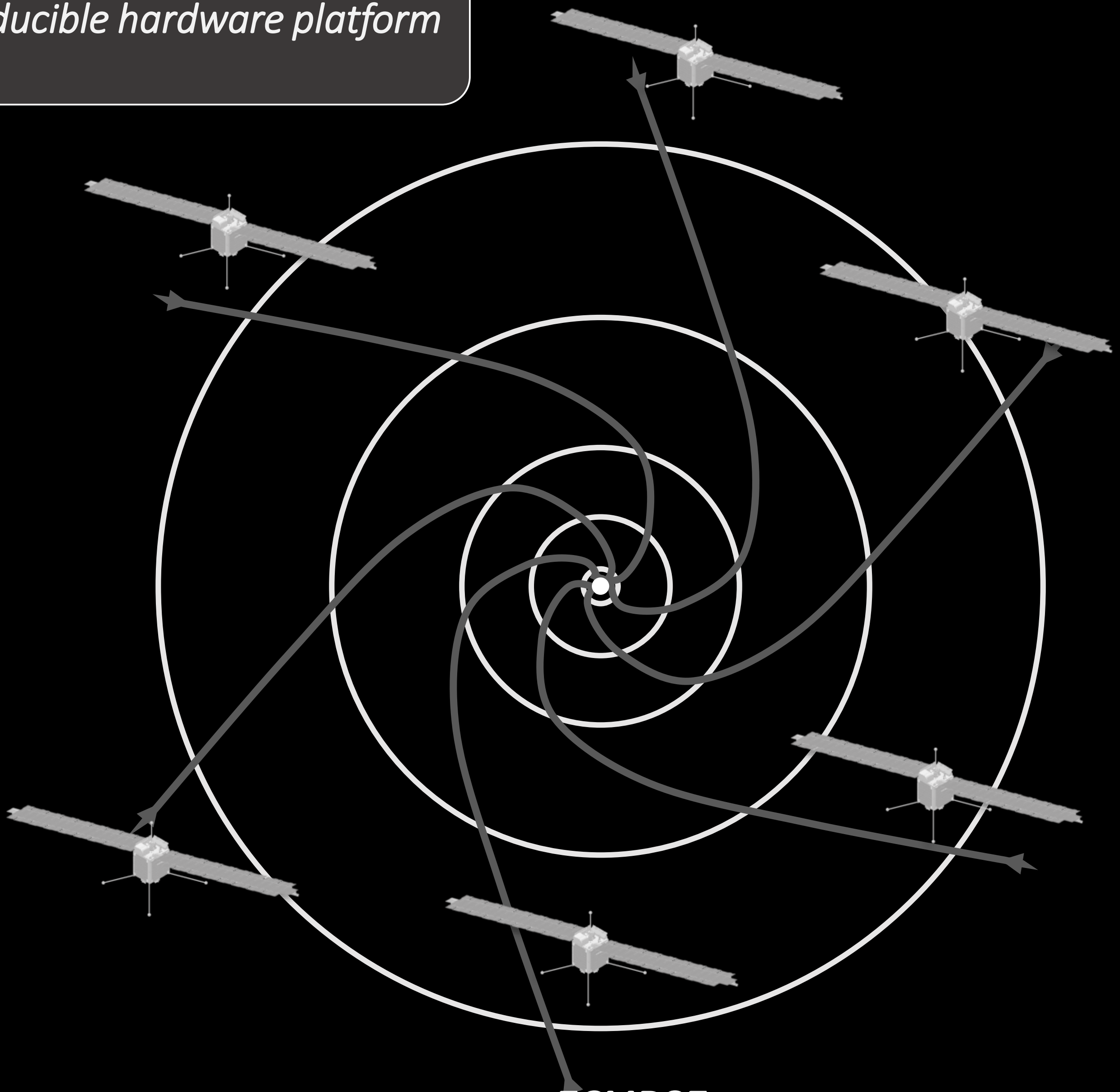


**Image courtesy of NASA JPL/Caltech*



VOYAGER
(825kg / SC)

ECLIPSE
(~250kg / SC)

THE SPACECRAFT AND PAYLOAD

FLIGHT SYSTEM DRIVERS AND CONCEPT OF OPERATIONS

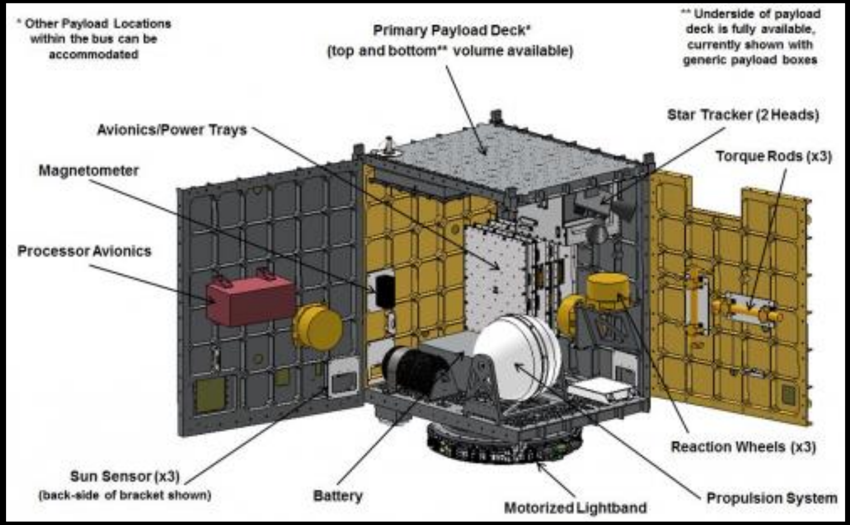
- Low-cost, multi-use spacecraft platform concept for multi-location science across the solar system
- Target mission duration: 10-15 years
- The mission architecture consists of multiple spacecraft deployed at the same time or within a narrow launch window, with each spacecraft targeting multiples destinations throughout its mission duration
- The spacecraft should:
  - Be capable of operating over a broad spectrum of space environments: radiation, thermal, power availability, etc. (however intent is not to design for extreme space environments)
  - Support solar electric propulsion for efficient transit over long distances
  - Accommodate a set of miniaturized instruments suited to perform science across the solar system

COTS SPACECRAFT BUS

- Utilizing an adaptable COTS spacecraft bus is a core element to the ECLIPSE platform
- Multiple options are currently available capable of rapid development schedules:
  - Northrop Grumman LEOStar-2: 250kg and up
    - Example missions: GALEX, SORCE, AIM
  - Millennium Space System AQUILA: 200kg and up
  - Advanced Solutions, Inc. ASI-150EP: 180kg and up

NGC LEOStar-2

MSS AQUILA



ASI 150EP [11]

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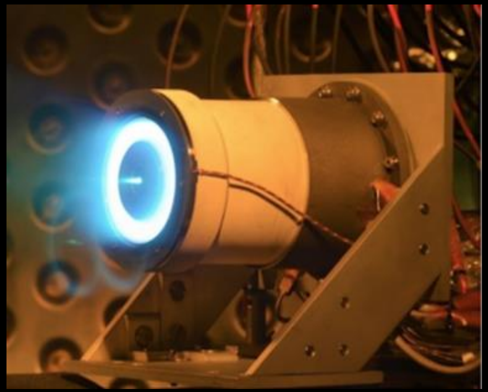
SOLAR ELECTRIC PROPULSION…ON A SMALL SCALE [1/2]

- Recent advances in electric propulsion thruster systems and compact deployable solar array systems have paved the way for highly capable solar electric propulsion (SEP) systems on small to medium spacecraft
- The JPL developed Magnetically Shielded Miniature (MaSMi) Hall thruster offers long duration thrust capability at relatively low powers in a small package
- The recent commercialization of the MaSMi technology through Apollo Fusion portends a high performance, low-cost small satellite integrated SEP system available in the very near future



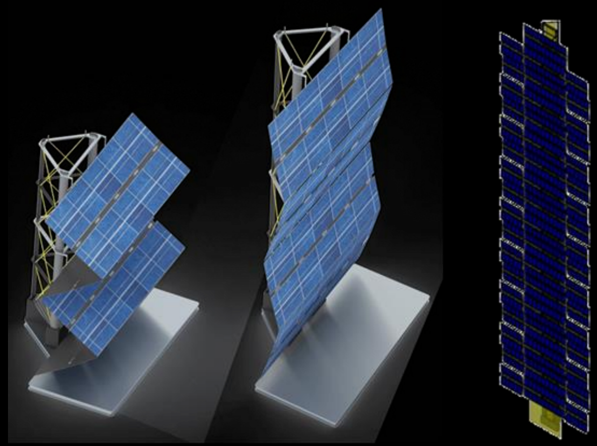
JPL MaSMi Thruster [1]

Apollo Fusion AXE Engine [2]

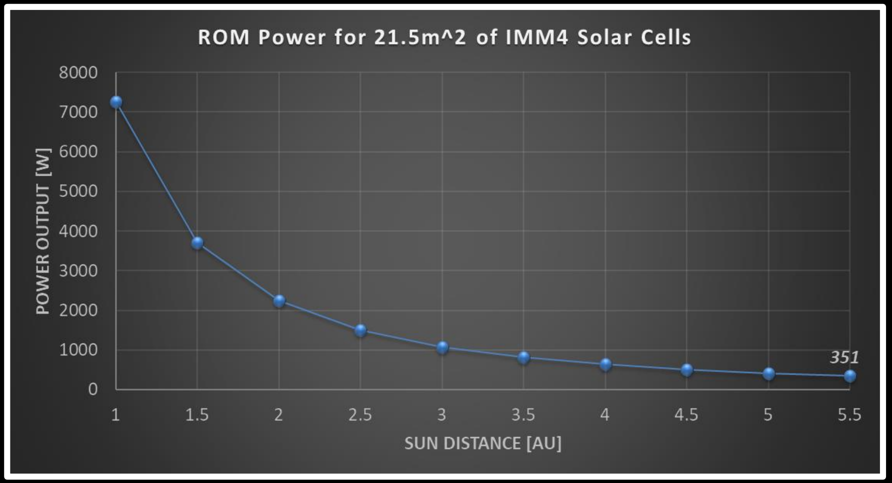
** Numbered references provided at end of presentation*

SOLAR ELECTRIC PROPULSION…ON A SMALL SCALE [2/2]

- To support the SEP system at sun distances much further than those typically traversed by small satellites, innovative solar array solutions are required.
- MMA Design has built up a successful flight heritage history for high power deployable solar arrays for small satellites, and their latest rHaWK concept will further expand their capabilities.
- The once infeasible concept of a small satellite generating hundreds of Watts at Jupiter for its SEP system will soon be an achievable reality.



MMA rHaWK Solar Array Concept [3]



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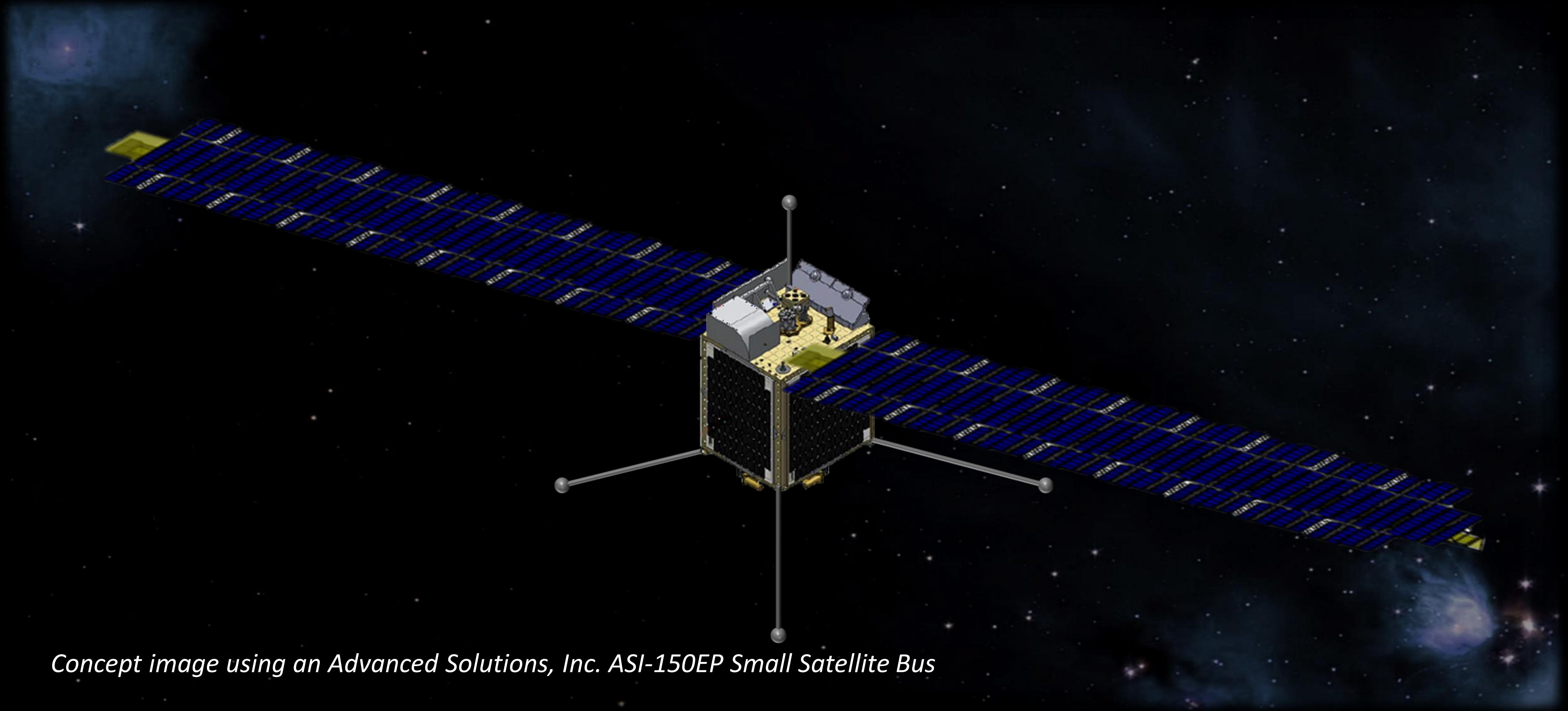
EXAMPLE SPACECRAFT CONFIGURATION



Concept image using an Advanced Solutions, Inc. ASI-150EP Small Satellite Bus

PAYLOAD MOTIVATION

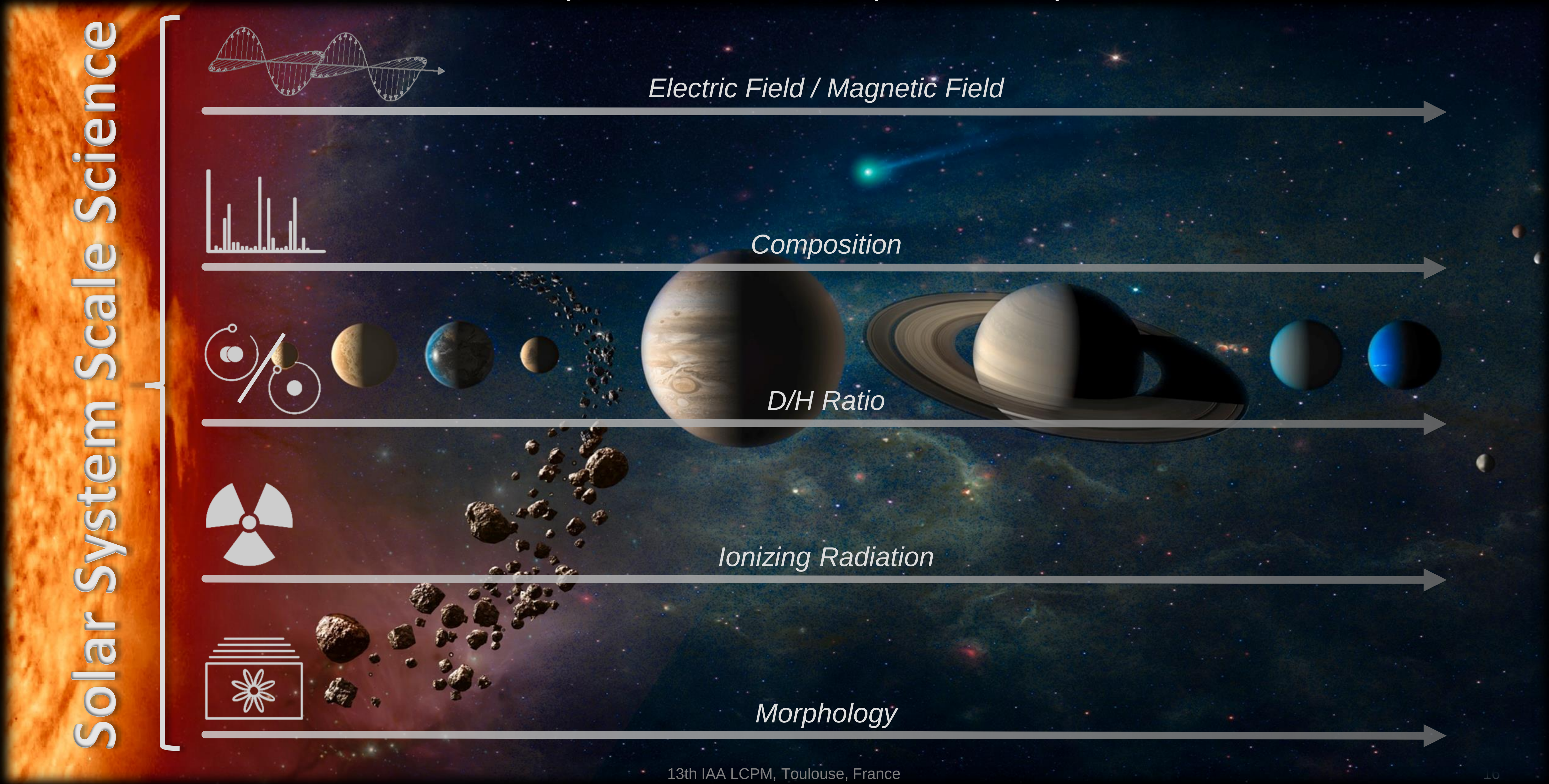
Science Goal

- The instrument selection should be focused on accomplishing distributed science through consistent measurements at multiple locations throughout the solar system
- The instruments should be diverse yet complementary to obtain cross-cutting measurements that address questions of astrophysics, heliophysics, and planetary science

Implementation Goal

- The guiding strategy is to achieve the most meaningful science at a low cost, i.e. maximizing “science return per dollar”
- Low cost/low mass motivates the use of miniaturized, solid state based instruments to reduce the need for complex and complex mechanisms, optics, deployables, etc.
- Given the low-cost approach, a focus is placed on the use of heritage instruments and/or technologies to reduce the significant resources often required for instrument development

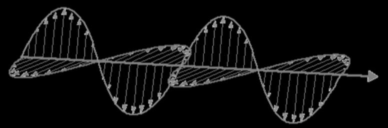
A clearer portrait of our solar system can be attained through measurements across the system, at interplanetary distances

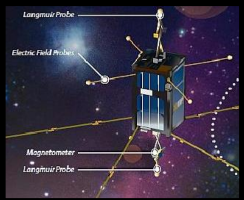


SAMPLE PAYLOAD SUITE

Science Measurement	***Example Instrument***

Electric Field / Magnetic Field



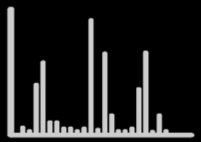


B-Field Measurement: Compact Vector Helium Magnetometer [4]
- JPL
- 10cm x 10cm x 5cm
- 0.5 kg
- 2 W

E-Field Measurement: DICE EF Probe [5]
- Utah State/ASTRA
- 10cm x 10cm x 5cm
- 4 kg
- 2 W

Flight Heritage:
YES (both)

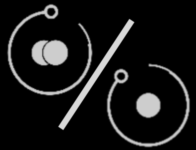
Composition

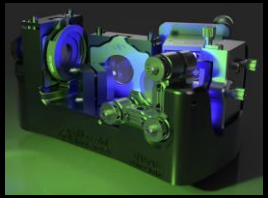


Hyperspectral Imaging: Hyperscout [6]
- Cosine
- 10cm x 10cm x 10cm
- 1.1 kg
- 11 W

Flight Heritage:
YES

D/H Ratio

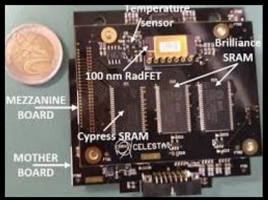




D-H Ratio Measurement: Spatial Heterodyne Spectrometer (SHS) [7]
- JPL (S. Hosseini)
- 10cm x 20cm x 20cm
- 5 kg
- 14 W

Flight Heritage:
NO *(in development)*

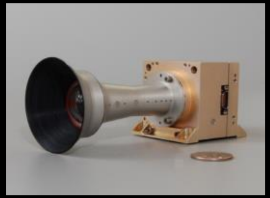
Ionizing Radiation



Radiation Monitor: Celesta RadMon [8]
- CERN
- 10cm x 10cm x 2cm
- 0.1 kg
- 1 W

Flight Heritage:
NO *(in development)*

Morphology



Visible Imaging: ECAM-C50 [9]
- Malin Space Science Systems
- Camera: 13cm x 8cm x 6cm
- Electronics: 22cm x 12xm x 3cm
- 1.2 kg
- 8.5 W

Flight Heritage:
YES

Payload Total:
- 11.9 kg *(well within payload capability of proposed buses)*
- 38.5 W *(with all instruments on)*

- While examples show support the concept feasibility, note that some modifications may be necessary for some deep space applications, such as for radiation tolerance (shielding, upgraded parts, etc.) and reliability/lifetime (upgraded parts, etc.)
- Note: Some values approximations based on similar hardware

** Numbered references provided at end of presentation*

THE MISSION

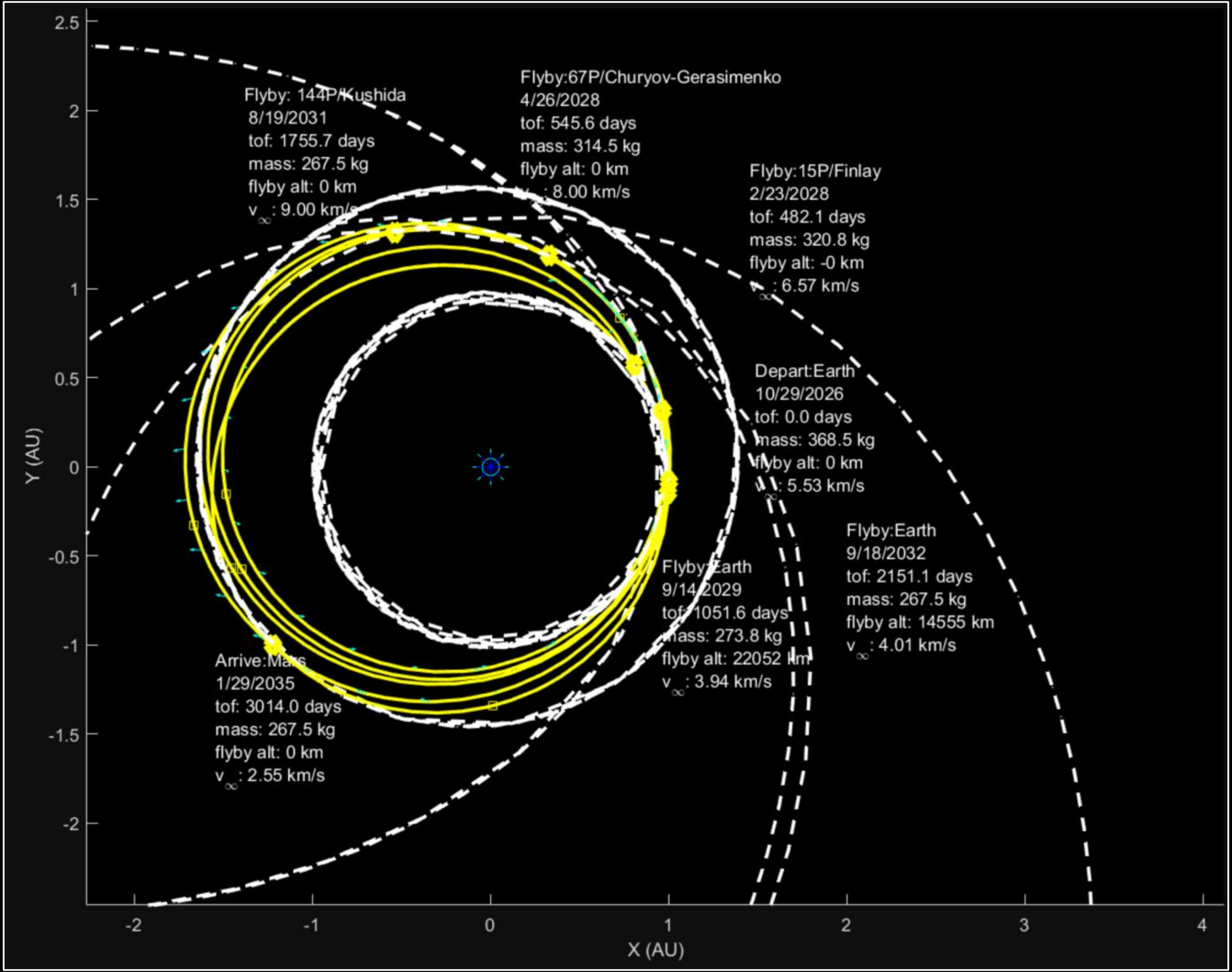
MISSION DESIGN

- Mission Design Objective: Maximize the number of target destinations
  - Fulfills study objective of understanding large populations of space objects
  - Achieved through multiple spacecraft launched together or very close together, each visiting many targets
  - Desire high target-to-spacecraft ratio
- While SEP trajectories were the primary focus, trajectories for chemical propulsion systems were also analyzed
- To validate the mission concept, two mission design examples were analyzed
  - Each launches between 2025-2028 and spans less than ten years
  - An initial global grid search of the parameter space is first performed using Star, a two-body patched conics software tool. After an initial guess is obtained using Star, a higher fidelity, low-thrust trajectory is obtained using Malto, modeling a MasMi thruster with 90% duty cycle

TRAJECTORY 1: COMET TOUR

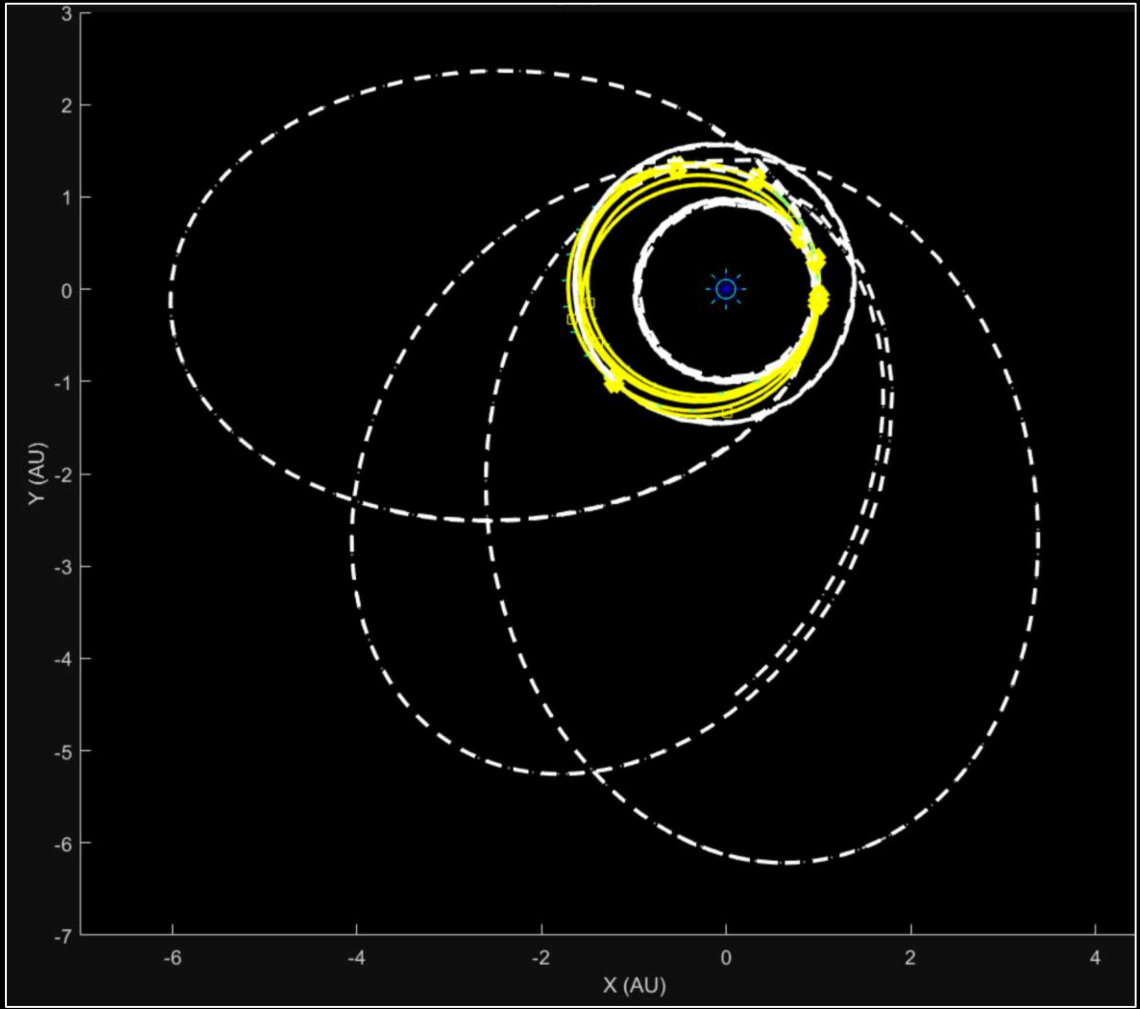
- Departs Earth in 2026 and flies by three comets at a hyperbolic excess speed < 9 km/s
- An Earth gravity assist a year after the last comet flyby positions the spacecraft on a direct course with Mars
- A gravity assist from Mars could allow for a rendezvous opportunity with the same planet approximately two years later using leveraging maneuvers

Body	Epoch	Flyby Speed (km/s)	Flyby Altitude (km)
Earth	10-29-2026	-	-
15P/Finlay	02-02-2028	6.57	-
67P/Churymov-Gerasimenko	04-26-2028	8.00	-
Earth	09-04-2029	3.94	22,052
144P/Kushinda	08-19-2031	9.00	-
Earth	09-18-2032	4.01	14,555
Mars	01-29-2035	2.55	0.00



TRAJECTORY 2: ASTEROID TOUR

- A fleet of spacecraft, each launched within a year of each other, each visiting several near-Earth asteroids (NEAs) within a ten-year mission span
- Each spacecraft rendezvous with the NEAs for a minimum of 30 days



CONCLUSION

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- Advancements in space technologies and the proliferation of small satellites has opened the door to achieving high science return per dollar
- The ECLIPSE spacecraft concept combined with innovative mission design strategies can enable a new paradigm of solar system magnitude science at a fraction of the cost and time of today’s flagship missions
- All technical elements of this approach are currently available or will be in the near future
  - Adaptable COTS buses
  - High performance, miniaturized instruments
  - Trajectories visiting multiple compelling science targets
- Reorienting to a new strategy is the core challenge
- Achieving the first unit is the critical first hurdle to overcome
- A detailed point design is key first step (including selecting a bus partner)

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